# Restoring Predevelopment Hydrology with Smart Stormwater Controls in Aiken, South Carolina

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**Abstract.** For decades, large quantities of stormwater runoff from the City of Aiken flowed at destructive velocities (exceeding 5 ft/s) into the Sand River, deeply eroding the channel in the downstream Hitchcock Woods. From 1990 to 2015, the City of Aiken commissioned several consultants to produce over a dozen studies to investigate viable solutions for the destructive erosion. Upon the recommendation from a collaborative Stormwater Task Force, the City of Aiken approved a stormwater implementation plan in 2018 which recommended 20 capital improvement projects sized to capture 58 ac-ft of stormwater in order to restore the river's predevelopment hydrology, with a goal of reducing stormwater velocities in the Sand River to reflect design considerations in the National Engineering Handbook (between 2.0 ft/s for fine sand channels and 4.0 ft/s for coarse sand channels). In November 2023, the City of Aiken completed construction on two underground detention vaults with a total storage volume of 25 ac-ft. These vaults were designed to capture stormwater runoff before it enters Hitchcock Woods and infiltrate as much stormwater runoff as possible; any additional stormwater will be released at a reduced flow rate compared to existing conditions. The 10-year, 24-hour storm event was selected to size the vaults because it was an achievable metric given numerous constraints such as available land, impacts to existing infrastructure and environmental resources, and available funding. The 10-year event also corresponded to typical stormwater requirements for new development. The vaults utilized the largest height, 15 feet, available for precast underground storage vaults in the marketplace. In addition to providing stormwater management below ground, a new public park was constructed on top of the buried vaults to be used as a gateway between the Hitchcock Woods and the City of Aiken.

## INTRODUCTION

Hitchcock Woods, located in the heart of Aiken, South Carolina, is one of the largest urban forests in the nation and is a South Carolina Department of Natural Resources Heritage Site home to several rare, endangered, and threatened species.

Storm drains within the historic section of the City of Aiken have been collecting and discharging stormwater runoff from 1,109 acres of urban watershed (which includes 327 acres of impervious surfaces) into the forest for decades. The stormwater has flowed into the Sand River carrying pollutants typical of urban runoff (such as fecal coliform, nutrients, and sediment) and also created erosion issues by carving a continuous linear canyon, toppling trees, and filling downstream wetlands with sediment as shown in Figure 1 and Figure 2.

From 1990 to 2015, the City of Aiken commissioned various studies (Table 1) to address the erosion within the Sand River, though none of these studies would move beyond the planning phase. The mitigation approaches ranged from diverting the piped stormdrain flows to other watersheds, installation of rain gardens in the headwaters, constructing a dam within the Hitchcock Woods, or extending the stormdrain pipes through the Hitchcock Woods.

In 2018, the City of Aiken adopted the Sand River Stormwater Implementation Plan to address the destructive runoff from the downtown area into the Hitchcock Woods. The approval came almost a year and a half after the mayor initiated the Stormwater Task Force in 2016, comprised of representatives of the Hitchcock Woods Foundation, citizen stakeholders, and city representatives. In 2017, the Task Force selected the engineering firm McCormick Taylor to serve as its technical stormwater consultant to develop a stormwa-

**Figure 1.** 20-to-30-foot vertical stream banks along the Sand River.

**Table 1.** Previous Sand River studies.

| Date Issued | Report Title | Consultant(s) |
|---|---|---|
| 1991, Feb. | Drainage Improvements at Dibble Road | Sirrine Environmental |
| 1992, Jan. | Stormwater Management Study for the City of Aiken: Sand River Drainage Basin | University of South Carolina; SC Land Resources Commission |
| 1994, Jul. | Sand River Stormwater Management Study | Woolpert, LLP |
| 1994, Sep. | Sand River Phase II Stormwater Management Study | Woolpert, LLP |
| 1995, Oct. | Stabilization Alternatives for the Sand River | Woolpert, LLP |
| 1998, Nov. | Sand River Stabilization Preliminary Engineering Report | Woolpert, LLP |
| 1999, Dec. | Sand River Channel Improvements | Woolpert, LLP |
| 2000, Sep. | Assessment of Stormwater Management & Stream Stabilization Issues in the Sand River Watershed | Pinnacle Group |
| 2001, Oct. | Sand River Dam | Woolpert LLP; Schnabel Engineering |
| 2002, Mar. | Need for a Comprehensive Stormwater Management Plan for Hitchcock Woods | Hitchcock Foundation |
| 2003, Jun. | Sand River Watershed Study | Woolpert, LLP |
| 2006, Aug. | Sand River Alternatives Report | Woolpert, LLP |
| 2007, May | SWPPP for Construction Activities at Sand River Channel Improvements | City of Aiken (Owner); Woolpert (Engineer) |
| 2009, Nov. | Geotechnical Data Report – Additional Borings and Infiltration Tests | Schnabel Engineering |
| 2013, Feb. | Sand River Headwaters Green Infrastructure Project | Clemson Center for Watershed Excellence |
| 2015, Apr. | Hydrological Evaluation of the Sand River Headwaters Stormwater Infrastructure | Clemson Institute of Computational Ecology |

**Figure 2.** Impacted forested wetlands filled with sand and debris.

**Table 2.** Current and predevelopment discharges into the Sand River.

| Current Conditions Watershed (cfs) | | | | | | | "Woods in Good Condition" Watershed (cfs) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Year | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year | 1 Year | 2 Year | 5 Year | 10 Year | 25 Year | 50 Year | 100 Year |
| 279 | 444 | 735 | 1008 | 1436 | 1822 | 2256 | 59 | 134 | 299 | 477 | 784 | 1084 | 1438 |

ter implementation plan for the Sand River. The stormwater implementation plan completed in early 2018 recommended 20 capital improvement projects, sized to capture 58 ac-ft of stormwater at an estimated cost of approximately $22 million (2017 dollars) as a way to restore the river's predevelopment hydrology. The storage volume was based on managing the developed watershed (curve number of 67) to a "woods good condition" land use (curve number of 55) for the 10-year storm event. The South Carolina Department of Health and Environmental Control (SCDHEC) precipitation values for Aiken County (5.3 inches of rainfall over a 24-hour period; SCDHEC 2005a) was selected as the design storm, as directed by the project owner. Table 2 summarizes the calculated predevelopment and post-development peak runoff rates computed using TR-20 models, and Table 3 lists the corresponding necessary storage volume computed using methodology outlined in the NRCS Technical Release-55 Report (NRCS 1986).

Several factors went into selecting the 10-year storm event. First, managing a 10-year event to pre-development conditions is a generally accepted and widely adopted stormwater requirement when considering new developments. The 10-year event was also a plausible management approach given the available funding and available land needed to implement such practices. The City of Aiken and stakeholders understood that given the size of the urban watershed, management of larger storm events would result in cost and land requirement that would be unachievable. The 10-year event was a balance between practicality and efforts to reduce the erosion within the Sand River. Furthermore, the managed 10-year stormwater flows were within close proximity to the stable velocities (allowable velocities for fine sand channel design is 2.0 ft/s and 4.0 ft/s for coarse sand channels) as listed in Table 8-4 of Part 654 Stream Restoration Design National Engineering Handbook (USDA-NRCS, 2007). This management goal, shown as the Ideal Discharge in Figure 3, was acknowledged as a starting point, and after implementation of the 10-year management program, the erosion could be monitored, and additional steps taken as necessary.

With the maximum allowable velocity of 4 ft/s, the existing channel dynamics were determined based upon the TR-20 results. An average 20 ft-wide typical section with vertical sidewalls and a longitudinal slope of 0.2% was modeled in FlowMaster to determine the current velocities within the upstream reaches of the Sand River. The results of this analysis indicated that the current 2-year discharge from the 10-foot diameter outfall pipe into the Sand River results in a velocity of approximately 5.3 ft/s. Upon implementation of stormwater management for the 2-year storm event, with no

**Table 3.** Storage volumes based on current and predevelopment discharges into the Sand River.

| Storage Volume Summary (acre-ft) | | | | |
|---|---|---|---|---|
| 1 Year | 2 Year | 5 Year | 10 Year | 25 Year |
| 26.76 | 35.06 | 47.46 | 58.22 | 74.12 |

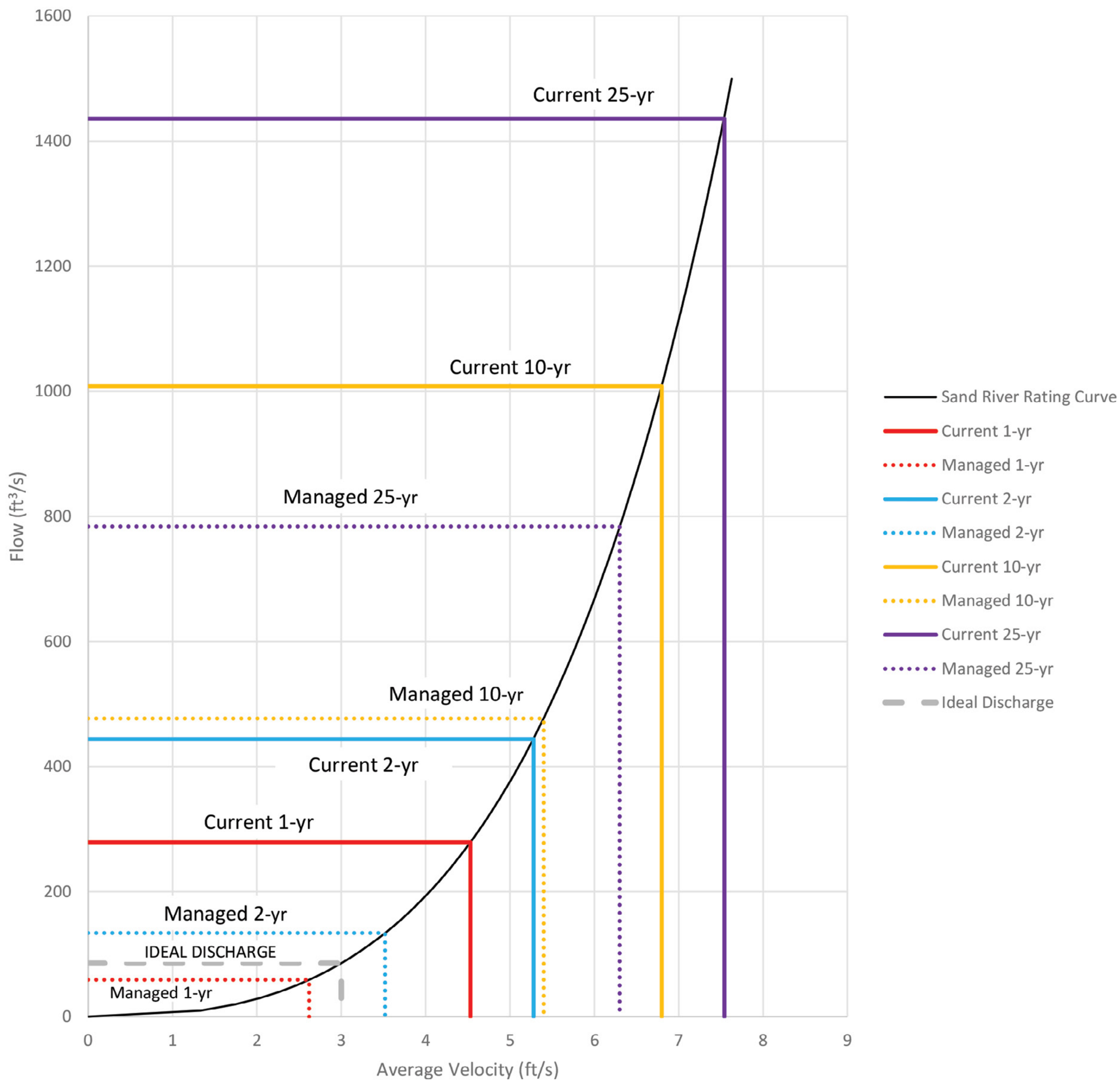


**Figure 3.** Current and proposed managed velocity within the Sand River.

change to the existing channel typical section (vertical walls), the velocity within the channel would be decreased to 3.5 ft/s.

In 2020, McCormick Taylor commenced work on one of the recommended projects, a system of connected underground concrete vaults which provides approximately 25 acre-feet of stormwater storage within the Sand River watershed. The vaults are positioned at the downstream end of Aiken's Sand River urban watershed, just upstream of major erosion in Hitchcock Woods. The subwatershed network draining to Hitchcock Woods is depicted in Figure 4, and the location of the detention vaults is shown in Figure 5. McCormick Taylor partnered with StormTrap (the modular concrete stormwater management vendor) and OPTI RTC (a technology company specializing in software that integrates sensors, forecasts, and environmental conditions to actively control stormwater infrastructure) during the design process. Two interconnected 15' DoubleTrap vaults were selected to store and control the stormwater runoff, as shown in Figure 6 and Figure 7.

The engineering firm also recommended the use of forecast-based real-time stormwater control technology, also called continuous monitoring and adaptive control (CMAC), to be installed on the underground system. By pairing the CMAC system with the DoubleTrap Vaults, vault efficacy is estimated to increase twofold by retaining water during and after storms, increasing infiltration, and only discharging in preparation for forecast storm events that exceed vault capacity, as illustrated in Figure 8. If the CMAC system was

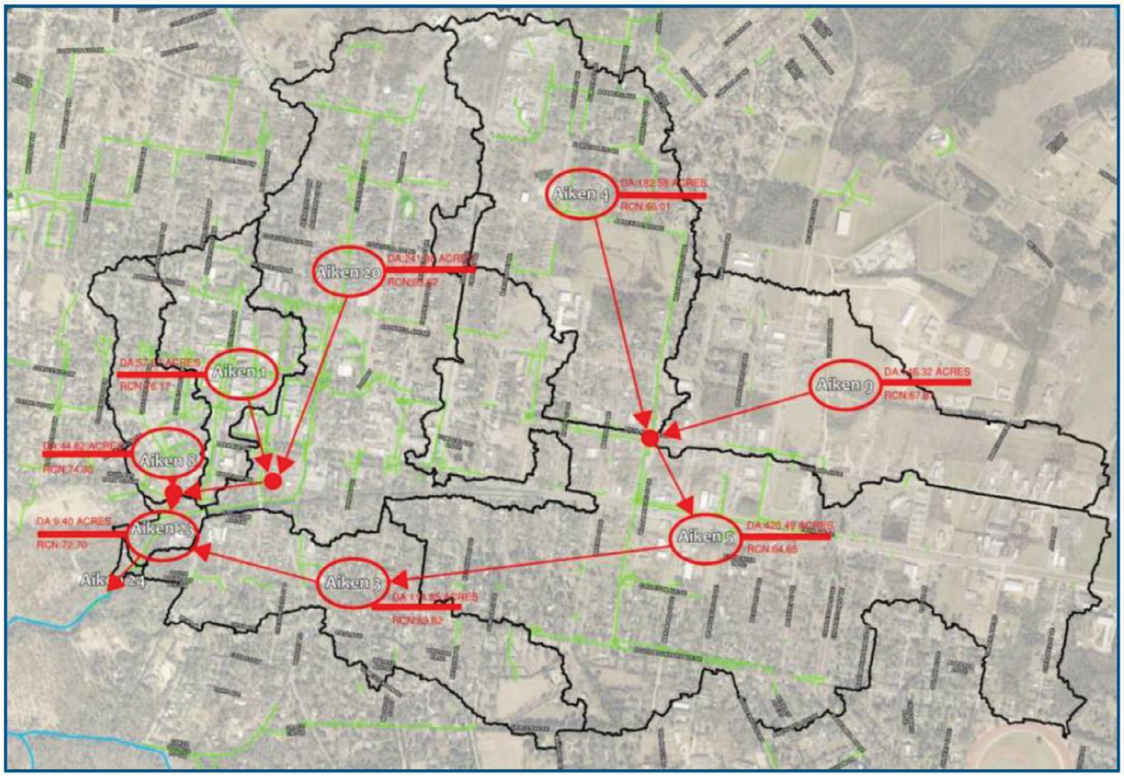


**Figure 4.** Project drainage area with TR-20 routing.

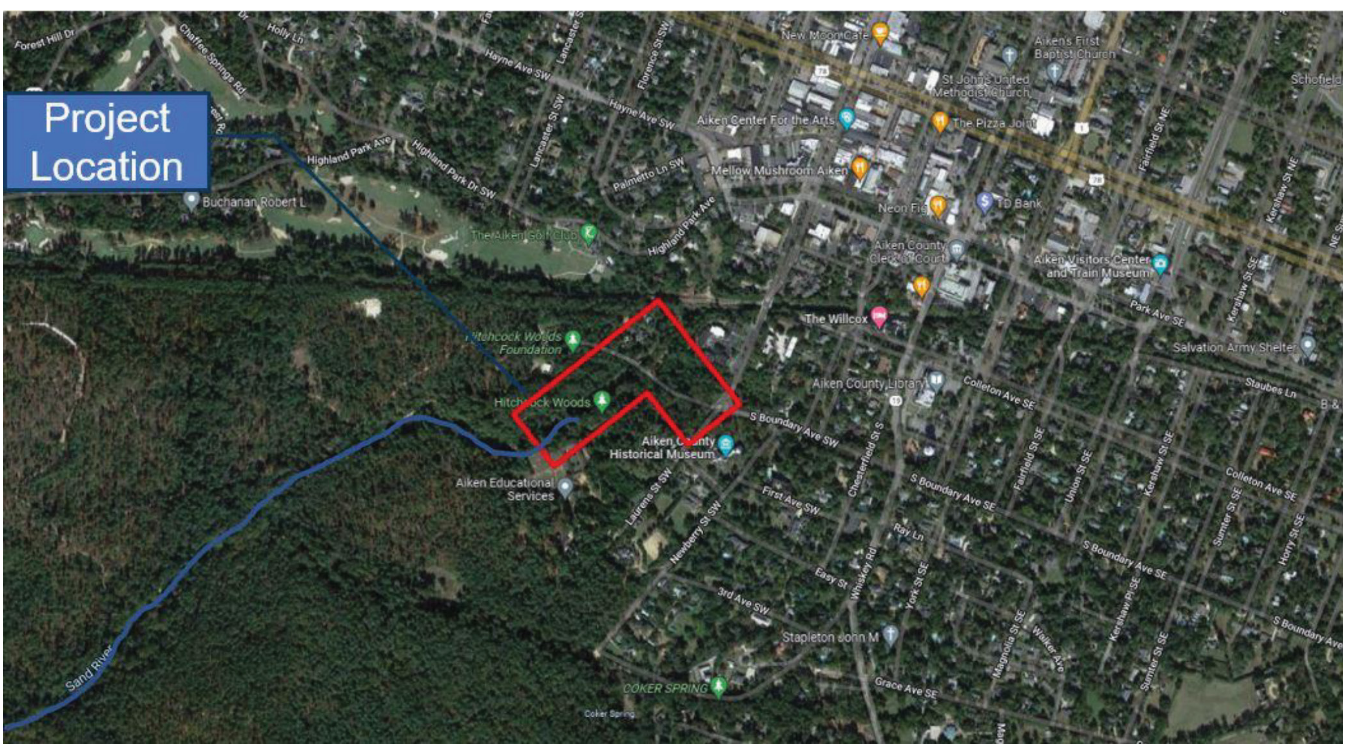


**Figure 5.** The underground detention vaults are located (red outline) between the entrance to Hitchcock Woods and the contributing drainage area from the City of Aiken.

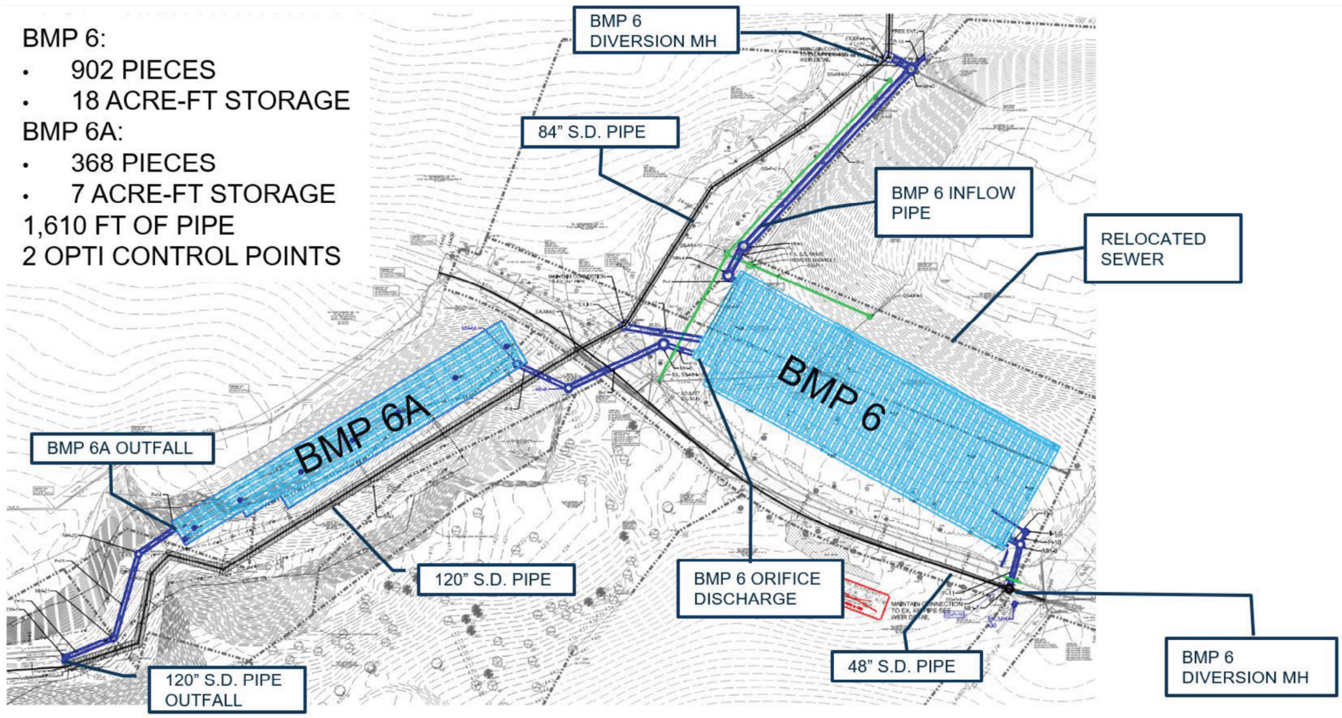


**Figure 6.** Schematic layout of the stormwater vaults.

not utilized, the type of vault used would either have to be a detention vault with a low flow orifice or an infiltration vault without a low flow orifice. Without a low flow orifice, the vaults would fill quickly for events exceeding the 2-year event, allowing runoff from larger storm events to bypass unmanaged into the Sand River. While a detention type BMP with low flow orifice would provide management of the larger events, it would not capture and infiltrate the 2-year or smaller storm events. Additionally, due to the size of the vaults and the infiltration duration taking several days to empty the vaults, in the event of frequent rain events, a solely infiltration-based BMP would often have limited storage. Using the CMAC system, these vaults can function as both an infiltration BMP capturing the majority of the 2-year or less events, and a hybrid infiltration and detention BMP for larger events.

The CMAC system operates in the Cloud and monitors the NOAA weather forecast for precipitation within the watershed. Seventy-two hours prior to a forecasted rain event, the CMAC system will compute the projected runoff volume based on the forecasted precipitation rate. The computed volume will be compared to the available storage within the vaults. If inadequate storage is available, the low flow orifices will open to allow a managed dewatering of the vaults until adequate volume is available to capture the forecasted rain event. For storm events less than the 2-year event, the CMAC system will keep the low flow orifices closed to allow for 100 percent capture of the runoff (as illustrated in Figure 9). For events between the 2-year and 10-year event, the CMAC system will operate in a hybrid state allowing flow through of the initial runoff, then will close the low flow orifices to capture the peak of the hydrograph, and then bypassing the remaining runoff once the vaults are full (as shown in Figure 10). For larger events exceeding the 10-year event, the low flow orifices will remain open acting as a detention facility, only closing once the projected runoff reaches a rate that can be stored by the vaults (as shown in Figure 11).

## CHALLENGES

One challenge associated with this project was the lack of available open space and the topography of the site. The project was situated on two unused parcels owned by the City of Aiken and the Hitchcock Woods Foundation. Expansion onto other parcels was not feasible due to private ownership, utilities, or presence of long leaf pine (*Pinus palustris*) forests which serve as habitat for red-cockaded woodpeckers (*Picoides borealis*), a threatened species. Because of the limited space, the consultant needed to identify the largest pre-cast concrete vault solutions in the market, which at the time was the DoubleTrap by StormTrap. While there are many underground vault options, the DoubleTrap was the only system to offer interior 15-ft height, thus maximizing the provided storage.

Further complicating the installation were the steep slopes adjacent to and within the excavation areas, as well as the depth of excavation needed to gain the necessary design elevation for the vaults. This resulted in the need for the contractor to install, on average, 20 to 40-ft tall temporary shoring walls (as shown in Figure 12) constructed of steel beams and timber lagging, utilizing soil anchors.

Many stormwater projects are designed to capture between 2.54 and 3.08 centimeters (1 and 2 inches) of runoff over the impervious drainage area. This system was designed to use as much of the available space as possible, with the combined storage volume capturing approximately 2.2 centimeters (0.86 inches) of runoff from the 141 hectares (349 acres) of impervious drainage area. With traditional passive stormwater management (detention ponds and non CMAC controlled BMPs), based on engineering experience, this site would likely underperform during medium to large storms given the contributing drainage area and the topography of the site which consist of steep slopes and property that is narrow in width.

Another challenge encountered during this project was the elevation change within the site. The larger of the vaults, BMP 6, sits significantly uphill from BMP 6A. The outlet invert from BMP 6 is higher than the top of BMP 6A. This means that although the vaults are hydraulically connected, water cannot be retained by outlet controls on BMP 6A only. These challenges necessitated a technology-enhanced solution for the project. Because of the high-sloped nature of the site, the CMAC systems must be configured such that BMP 6 passes flow to BMP 6A early in the storm, then the actuated gate at the BMP 6 outlet must close to mitigate peak flows and maximize infiltration. This required coordinating the release of one system with the other.

Logistics of delivering over 1,300 pieces that comprise the vaults, plus the gravel needed to backfill around the vaults proved challenging given the project location within Aiken's Residential Historic District. Because of the Aiken's narrow, tree-lined streets, tractor trailers were not allowed to take the most direct route from the interstate through the town and to the site. Having to take a circuitous route around the city resulted in continuous coordination with the precast plant, StormTrap, and the delivery trucks. As the site had no onsite staging area for multiple tractor trailers, an offsite staging area had to be established to queue the tractor trailers until the site was ready to accept their delivery.

The larger vault, BMP 6, is located within a vein of kaolin clay which prohibited infiltration. To allow for infiltration, 25-ft deep stone chimneys were installed to bridge the kaolin layer to access subsurface sand. This resulted in significantly high infiltration rates improving the effectiveness of the unit.

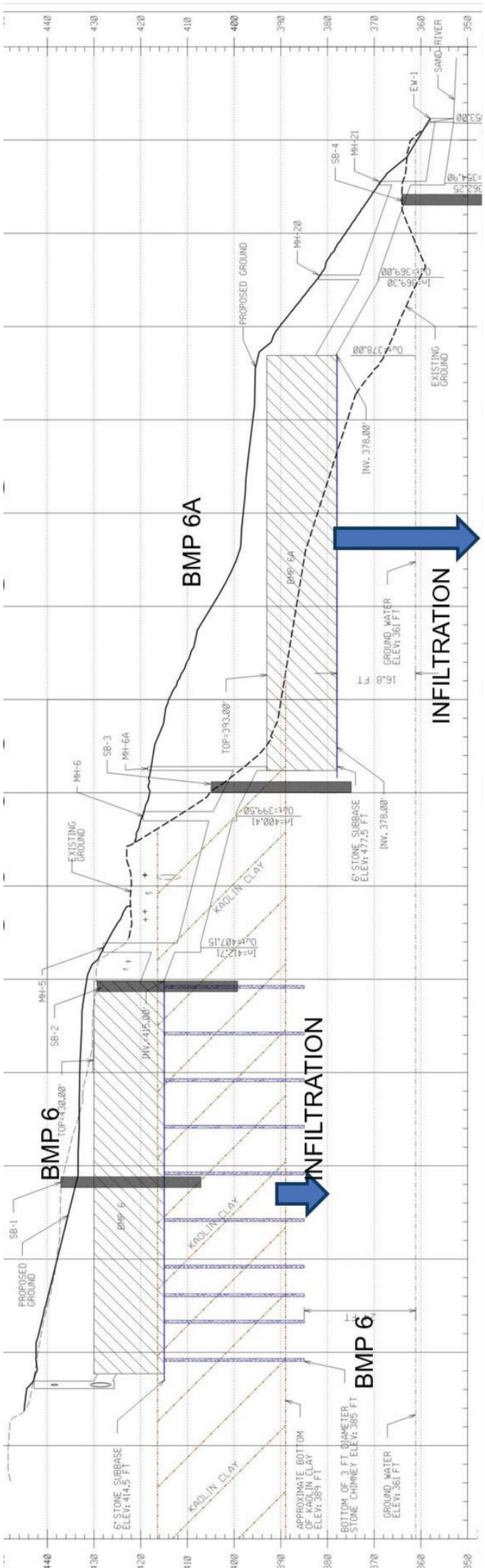


**Figure 7.** Profile of the stormwater vaults.

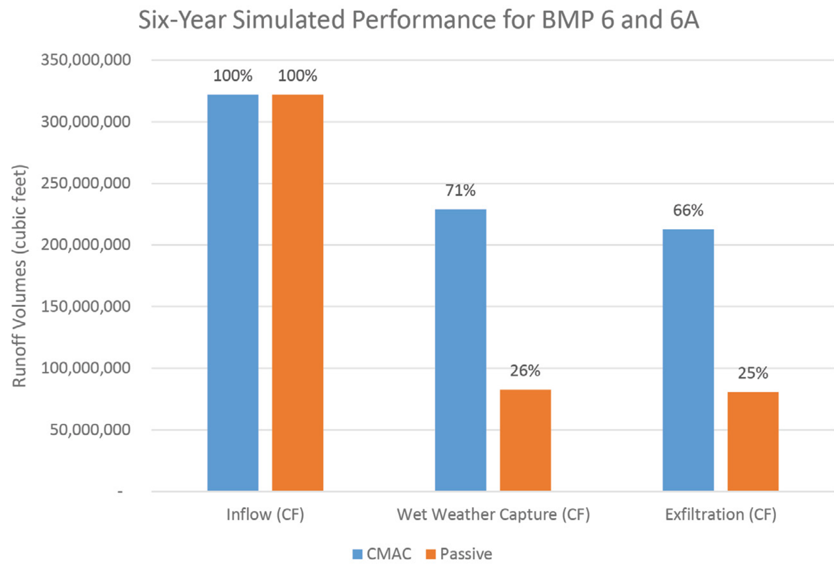


**Figure 8.** Expected CMAC improved outcomes for stormwater storage and treatment in vaults.

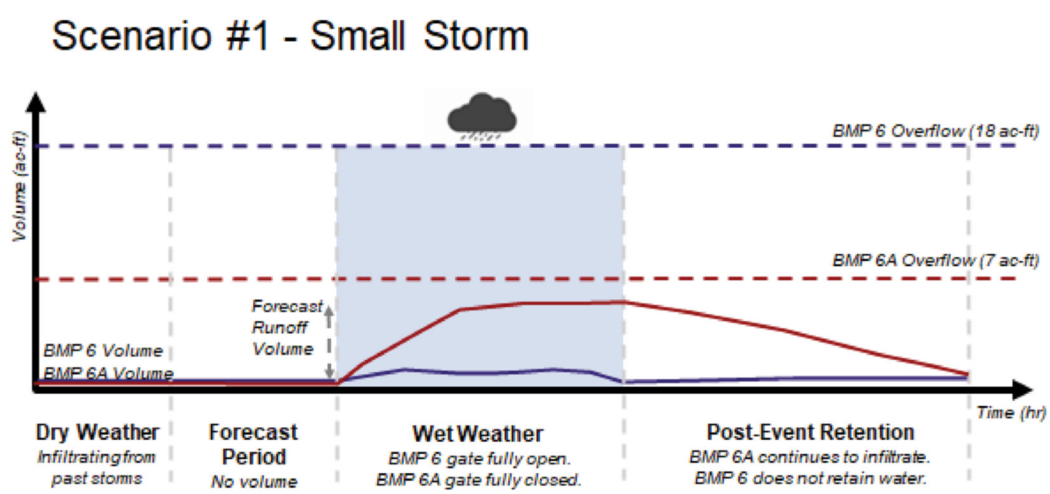


**Figure 9.** Illustrative CMAC response to less than 2-year storm events.

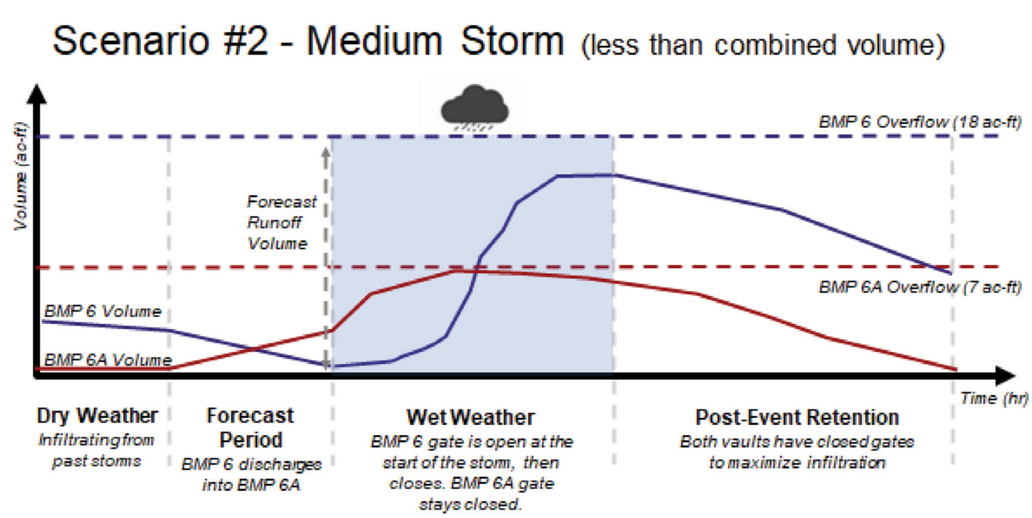


**Figure 10.** Illustrative CMAC response to approximately 2 to 10-year storm events.

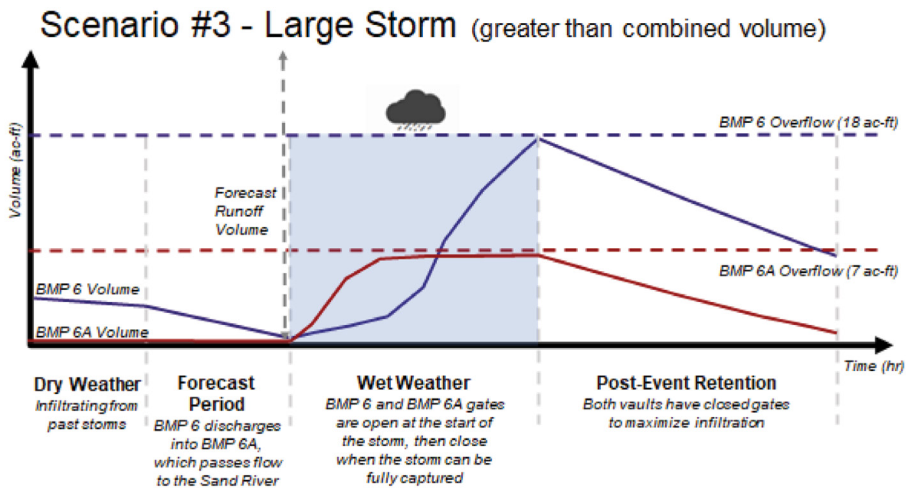


**Figure 11.** Illustrative CMAC response to greater than 10-year storm events.

**Figure 12.** Construction of the larger of the two pre-cast concrete vault systems, BMP 6.

As the site itself was very compact given the scale of the project, the contractor had to carefully sequence all operations to allow for adequate room to store the excavated soils which were to be placed back over top of the vaults to allow for a zero haul off project, as well as stage enough StormTrap vaults so that they could maintain production throughout each day as delivery of the units could be several hours apart.

## EVALUATION

Water quality and quantity monitoring for the project began January 2023. Water quality samples will be collected at the end of pipe and from upstream of the BMPs during wet weather events. Two groundwater monitoring wells will be sampled biannually (twice a year) to gauge effects to the groundwater quality and groundwater depth. The existing city surface water quality monitoring program for bacteria will be expanded and will include additional parameters such as petroleum, organics, total suspended solids (TSS), nitrates, and phosphates.

The City of Aiken will be looking at the stormwater volume captured versus the amount of stormwater volume infiltrated or detained through the system. Flow monitors will be installed at the two contributing pipes upstream of the vaults and the outfall into the Sand River to gage the decrease in flow rate into the Sand River during rain events.

This will allow the city to quantify the reduction of the discharge hydrograph into the Sand River. The Opti Dashboard will provide performance metrics that would compare the operational effects of the Opti System on the StormTrap system versus if the StormTrap system did not have any CMAC technology. Additionally, the Aiken is developing a monitoring plan for the erosion within the Sand River which may include grade stakes and visual observation of known landmarks within the channel.

## RESULTS

Years of water quality monitoring from several organizations (SCDHEC, City of Aiken, University of South Carolina-Aiken) have documented the Sand River's bacteria impairment. The watershed falls within an approved TMDL for fecal coliform bacteria (SCDHEC 2005b). Recent studies from the University of South Carolina, Aiken, found a positive correlation between fecal coliform pollution and stormwater runoff, higher concentrations of bacteria were found in the

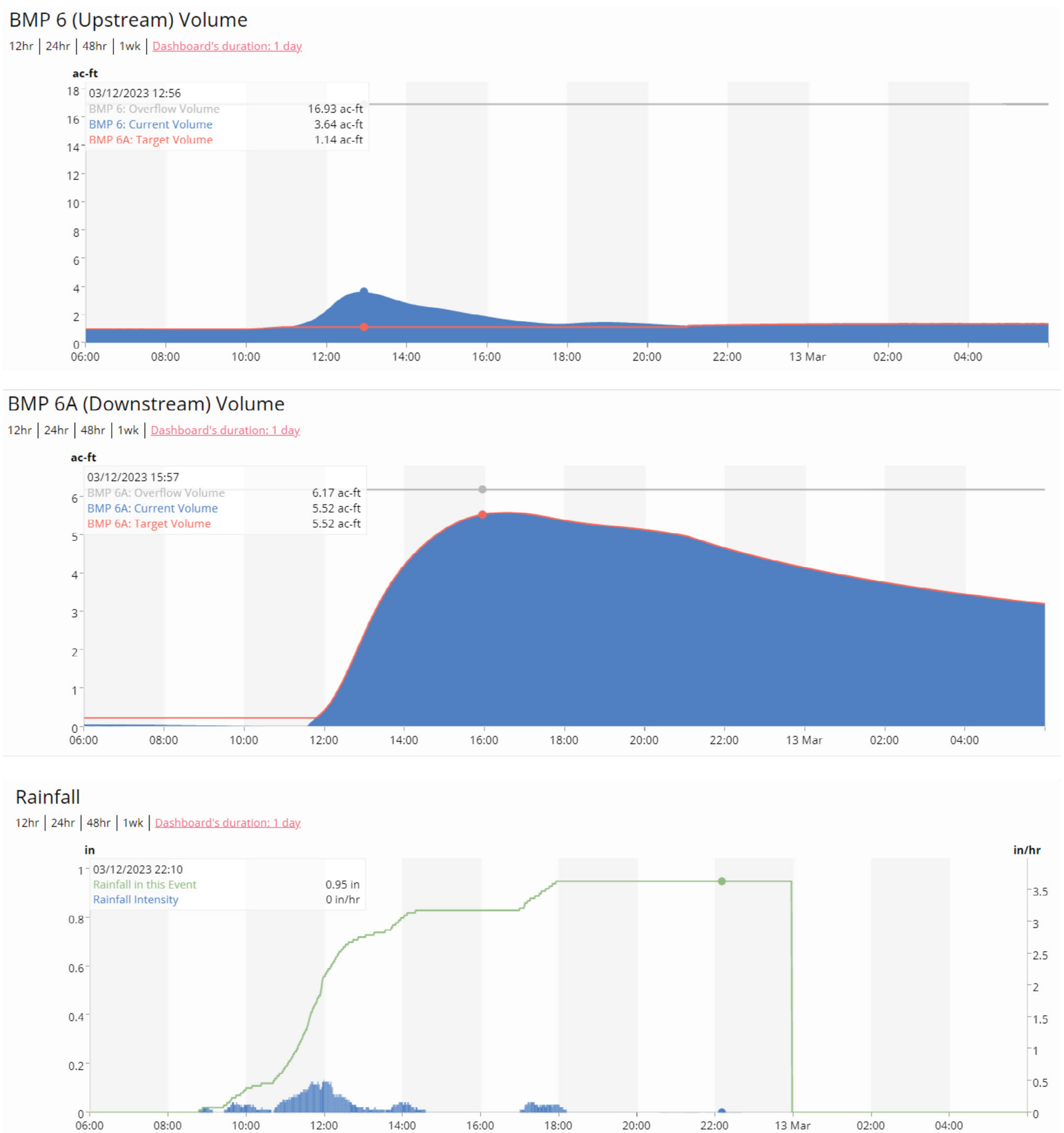


**Figure 13.** CMAC response to approximately 1-inch of rainfall.

Sand River than in Horse Creek, and the main sources of the bacteria were horse manure and human sewage (Harmon et al. 2014; Harmon and Yates 2018). Published bacteria removal rates for infiltration practices varies (as little as 10% to as high as 95% depending on the source), but the City of Aiken will be monitoring water quality as an ongoing, long-term process.

Figure 13 reflects the actual performance of the vault system (on March 12, 2023) following approximately one inch of rainfall. The system intercepted 100 percent of the runoff, allowing it to flow through BMP 6 and store and infiltrate the volume within BMP 6A. Through infiltration of the 2-year and smaller storm events, which are considered water quality first flush events, pollutants found in urban runoff (fecal coliform, nutrients, petroleum) will be filtered out and prevented from flowing into the Sand River to improve the river's water quality.

In addition to the stormwater vaults, the City of Aiken constructed a passive park in November 2022 on top of these facilities as part of the site restoration in order to provide a new, grand, entryway into Hitchcock Woods (Figure 14 and Figure 15). The design included pervious rubber sidewalks, demonstration pollinator gardens, a rain garden, and educational signage depicting the history of Aiken and Hitchcock Woods.

**Figure 14.** CMAC response to approximately 1-inch of rainfall.


**Figure 15.** CMAC response to approximately 1-inch of rainfall.

At this time, the Aiken stormwater vaults are the largest underground stormwater management system installed in South Carolina, as well as the first use of CMAC technology within the state. This is also the first time the OPTI RTC CMAC system has been paired with an underground management system like StormTrap. Due to the project magnitude, project leaders believe this will be a model for other municipalities struggling with stormwater and for protecting surrounding historical landmarks.

## ACKNOWLEDGMENTS

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